National Aeronautics and Space Administration

Stratospheric Circulation Changes Associated with the Hunga Tonga-Hunga Ha'apai Eruption

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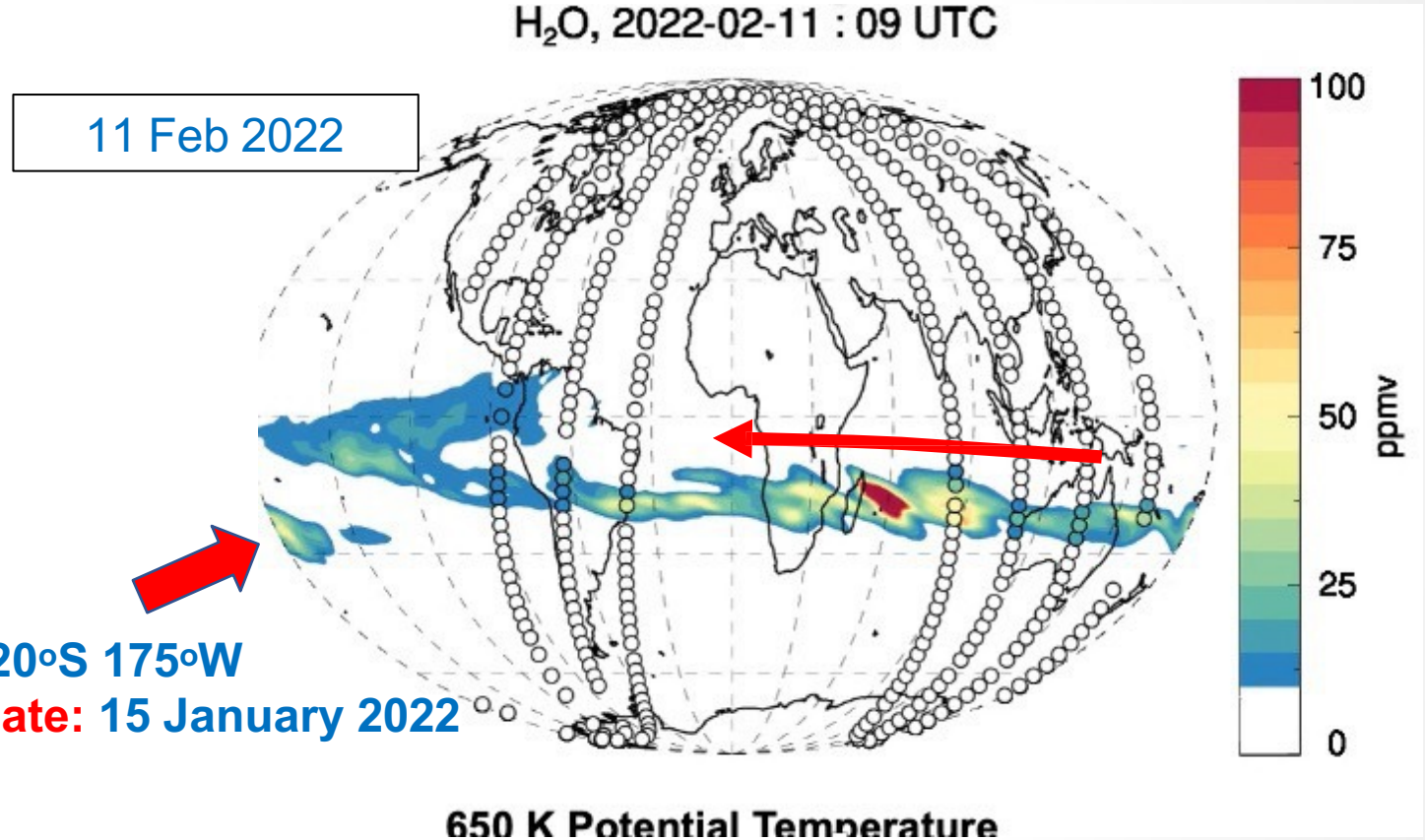


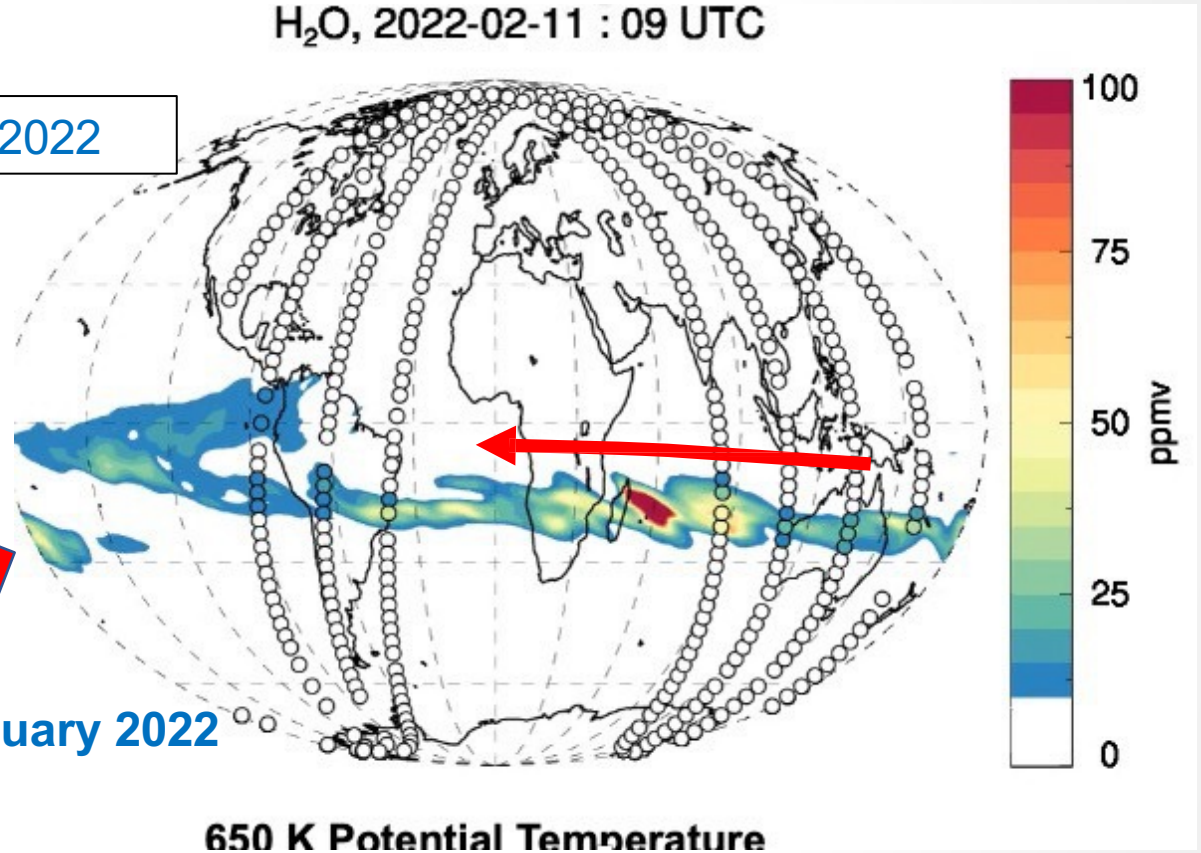
M2-SCREAM: MERRA-2 Stratospheric Composition Reanalysis of Aura Microwave Limb Sounder

MERRA-2: Modern-Era Retrospective analysis for Research and Applications, Version 2

Stratospheric Circulation Changes Associated with the Hunga Tonga-Hunga Ha'apai Eruption

Outline:

1. The data going into MERRA-2 can capture the effects of the Tonga water vapor, even though MERRA-2 physics does not include the water vapor perturbation
2. Evaluation of the changes in the MERRA-2 winds, temperatures, and circulations associated with the Tonga water vapor perturbation



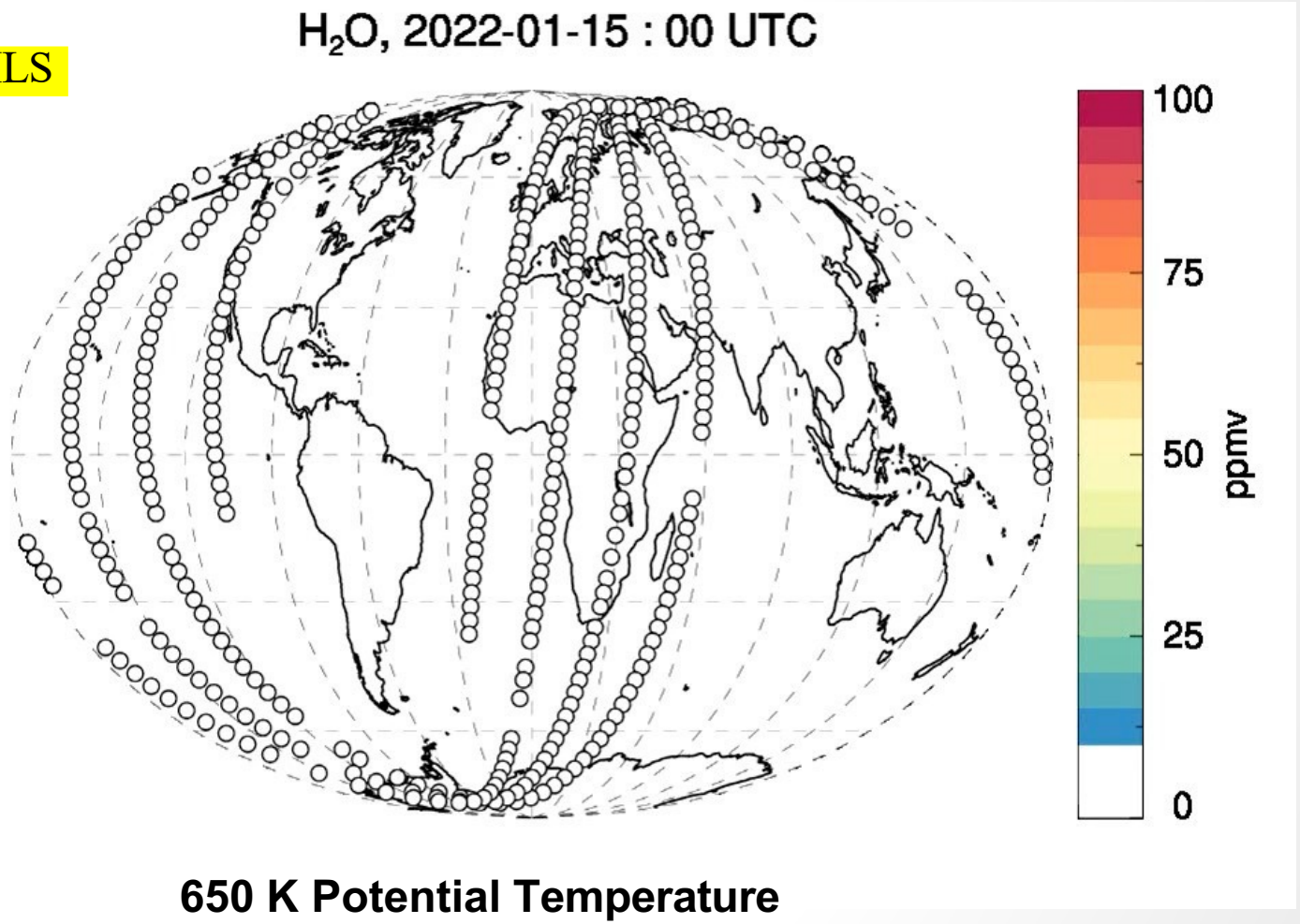
M2-SCREAM: MERRA-2 Stratospheric Composition Reanalysis of Aura Microwave Limb Sounder

MERRA-2: Modern-Era Retrospective analysis for Research and Applications, Version 2

Water vapor from eruption spreads around the globe

Special **M2-SCREAM** assimilates the MLS water vapor measurements.
K. Wargan, 2022

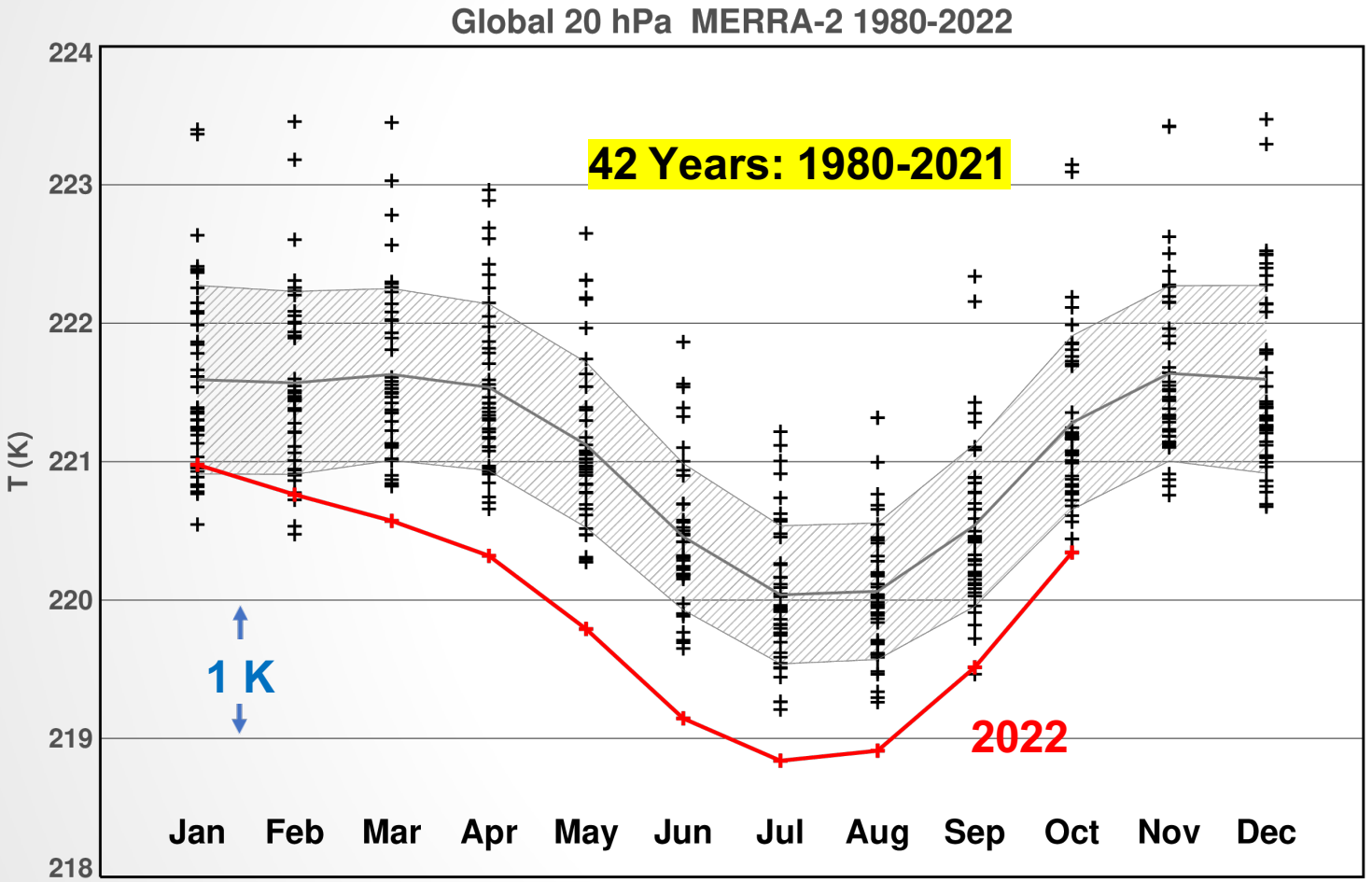
Location: 20°S 175°W
Eruption Date: 15 January 2022



650 K Potential Temperature
Surface ~26 km

Note: Standard GMAO assimilation products do not assimilation middle atmosphere water vapor.

MERRA-2: unusually low global temperatures at 20 hPa

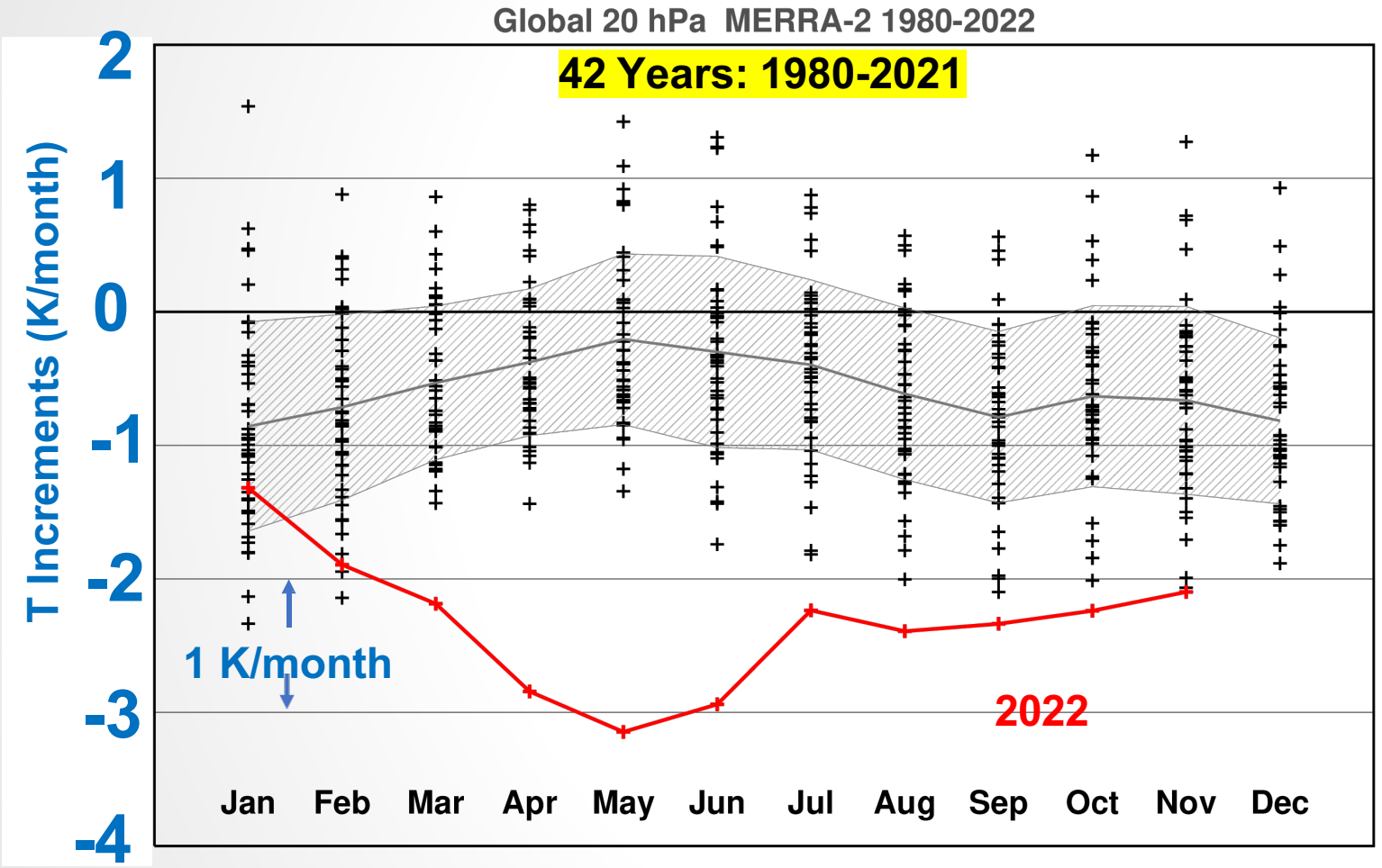


Global Mean Temperature
20 hPa (~27 km)

MERRA-2
Monthly Averaged

2022 global temperatures at 20 hPa were much lower than in past years

Missing water vapor cooling in 2022 created extreme temperature increments at 20 hPa



Global Mean Temperature Increments
20 hPa (~27 km)

MERRA-2
Monthly Averaged

Data analysis generated tendencies can capture missing radiative effects

Thermodynamic Equation

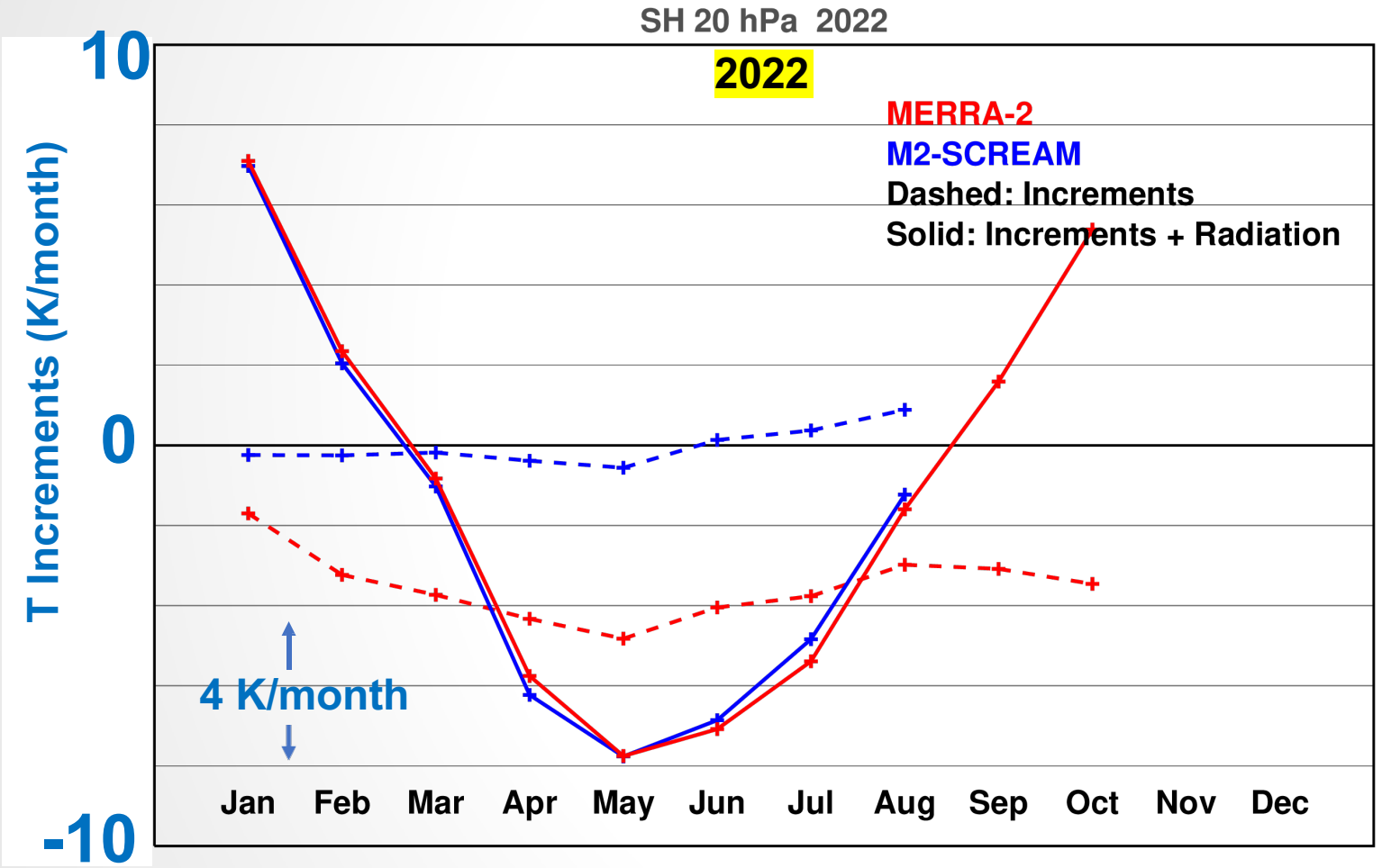
DT/dt = Dynamics Tendency + Radiative Tendency + Data Analysis Tendency

Horizonal and vertical advection

Corrected Radiative Tendency

Also known as increments

MERRA-2 data analysis increments capture the perturbed water vapor cooling.



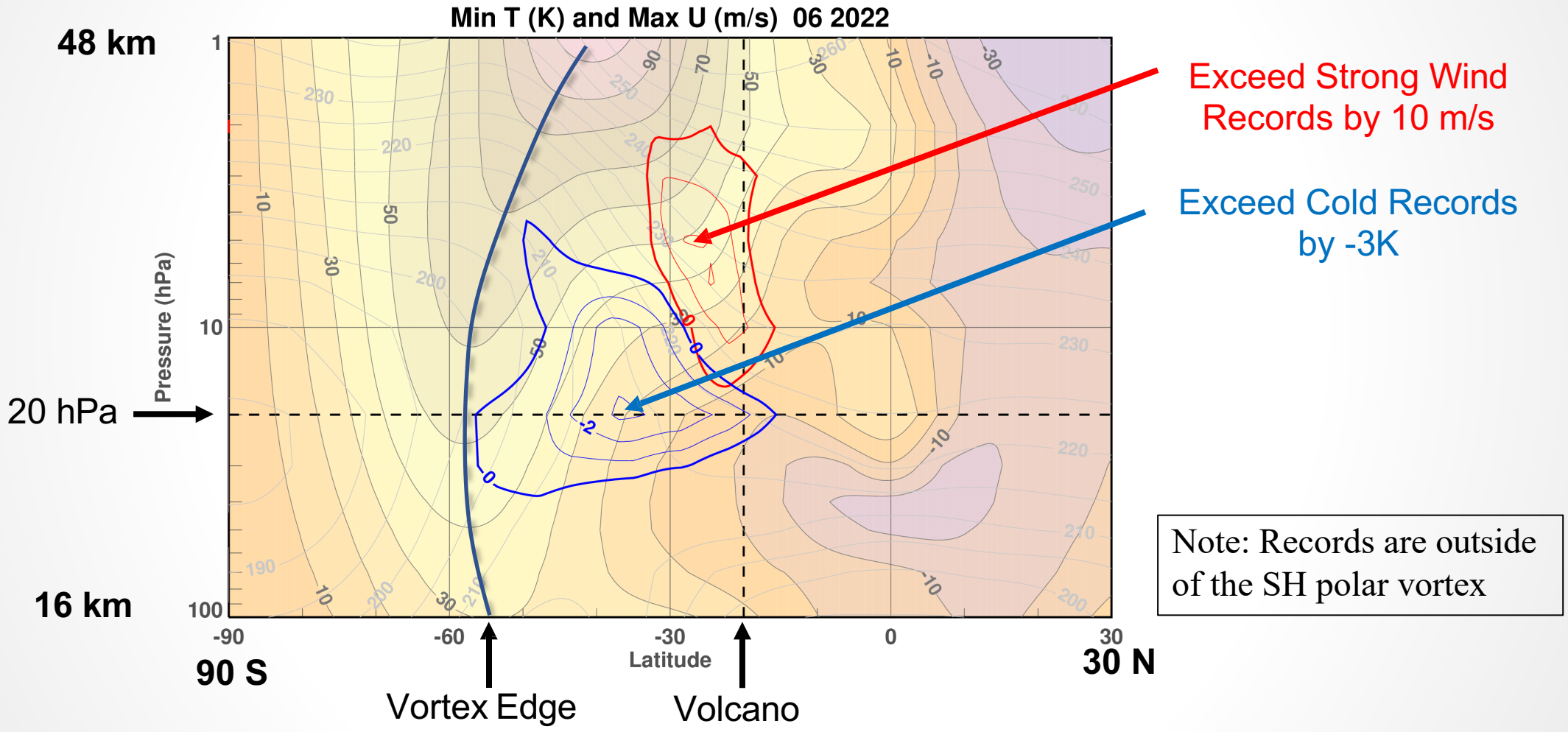
Southern Hemisphere
Mean Temperature Increments
20 hPa (~27 km)

Monthly Averaged

M2-SCREAM
Increments near zero
Strong radiative cooling

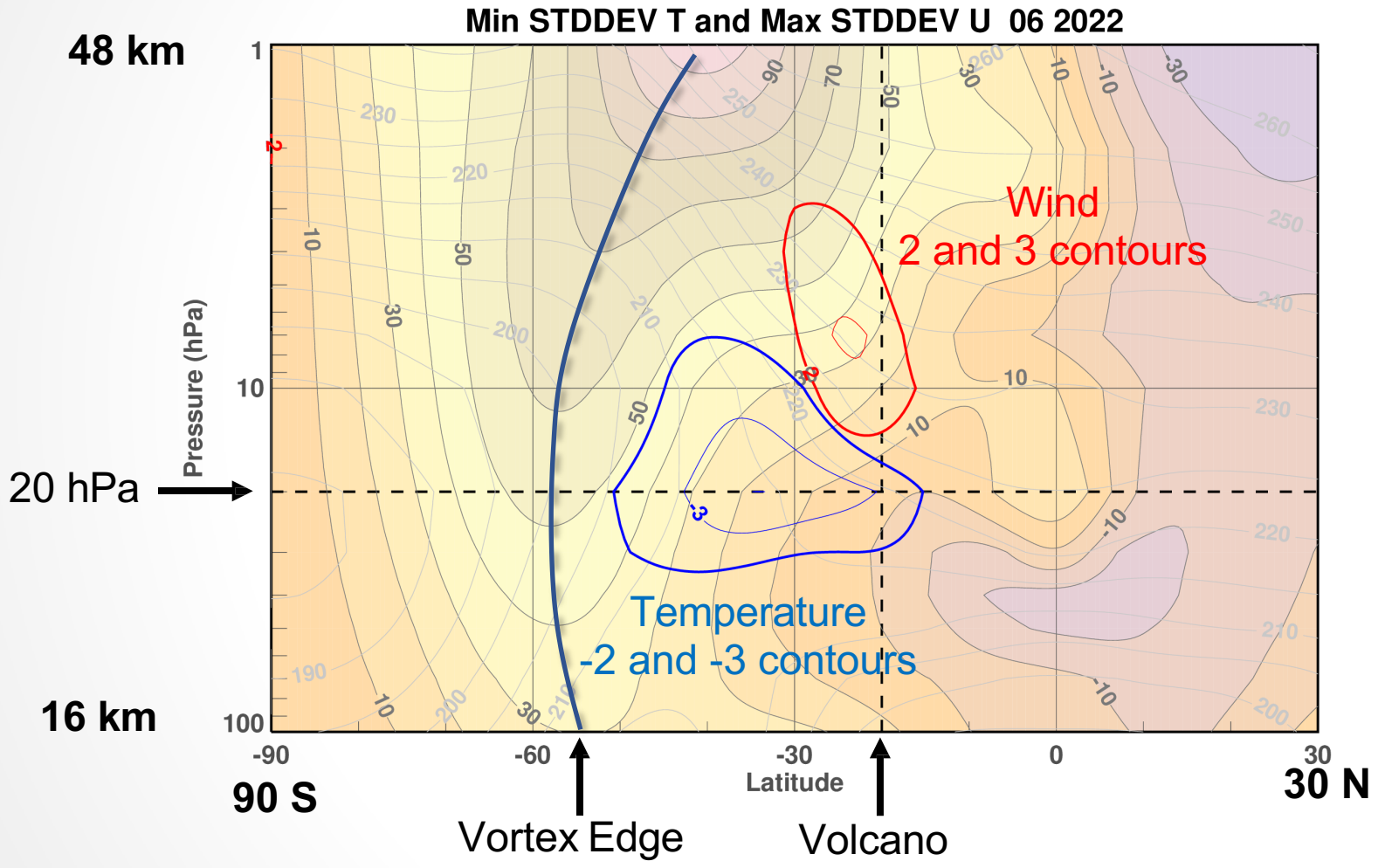
MERRA-2
Increments large
Sum is strongly cooling

Record low temperature and strong winds were seen in June 2022



WRT 1980-2021 MERRA-2

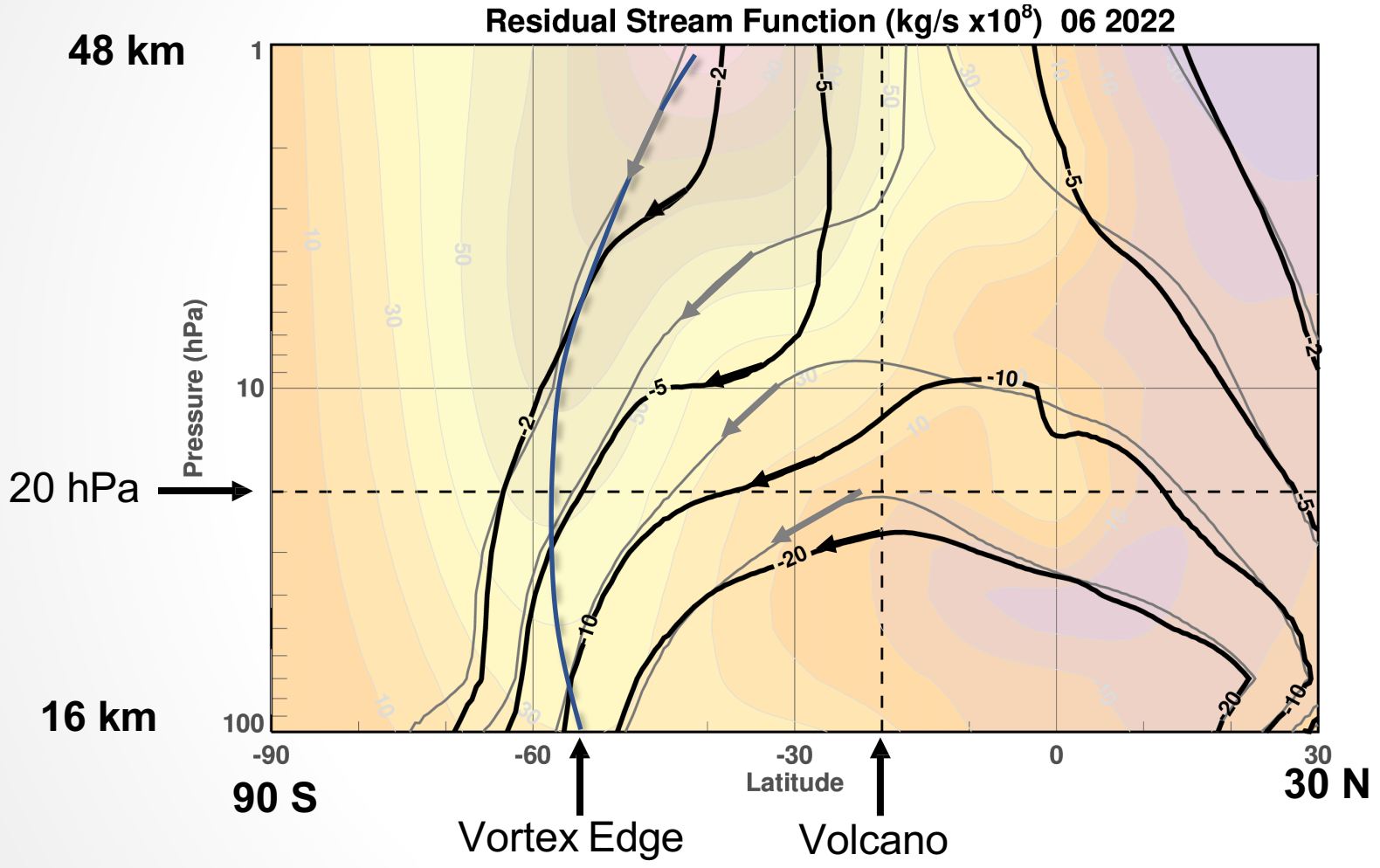
Temperatures were more than 3 standard deviations below the mean
Winds were more than 3 standard deviations above the mean



June 2022

WRT 1980-2021 MERRA-2

The residual mean stream function was greatly distorted in June 2022



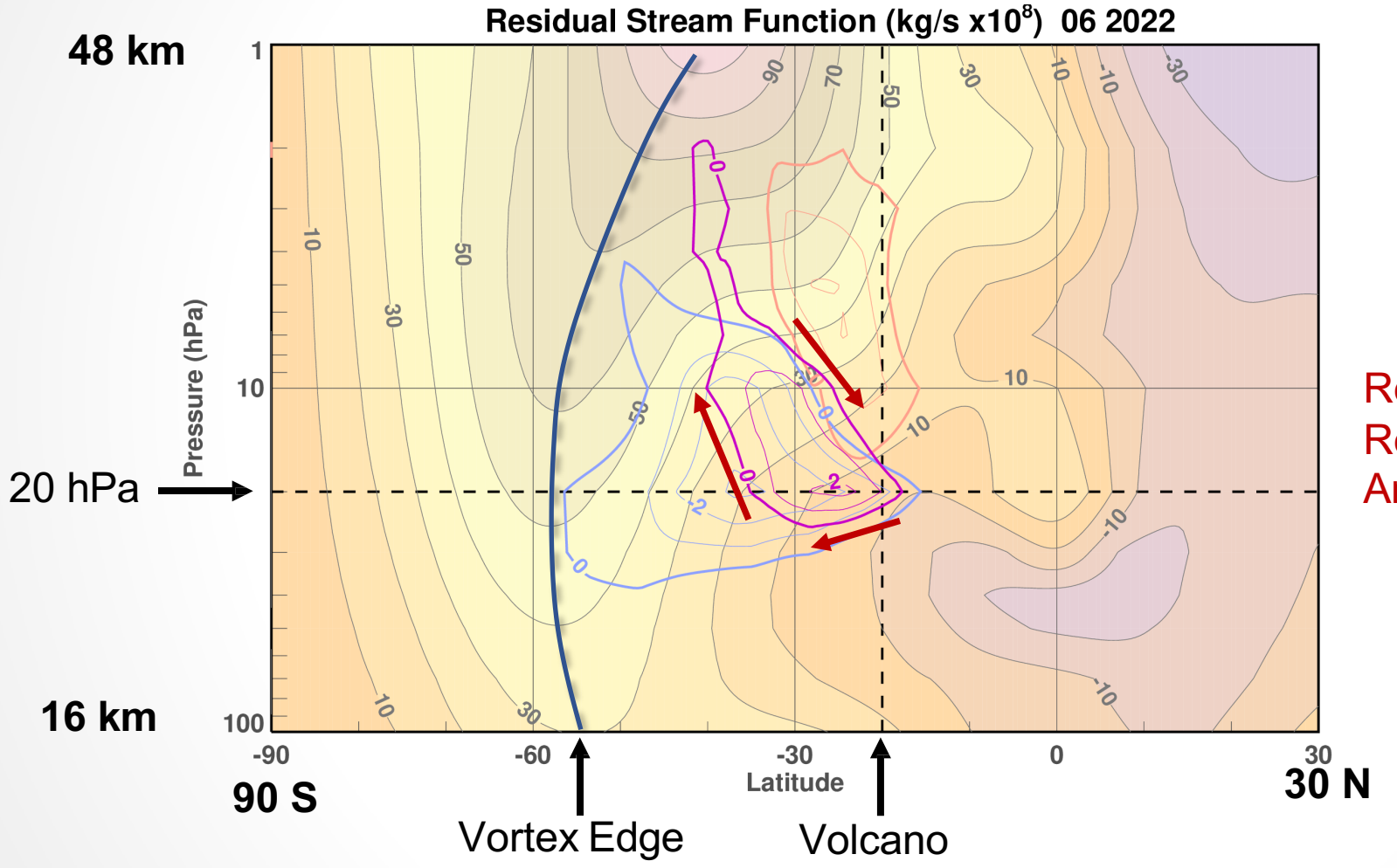
June 2022

Gray
1980-2021 Average

Black
2022

WRT 1980-2021 MERRA-2

The residual circulation had a record strong anomaly near the volcano location



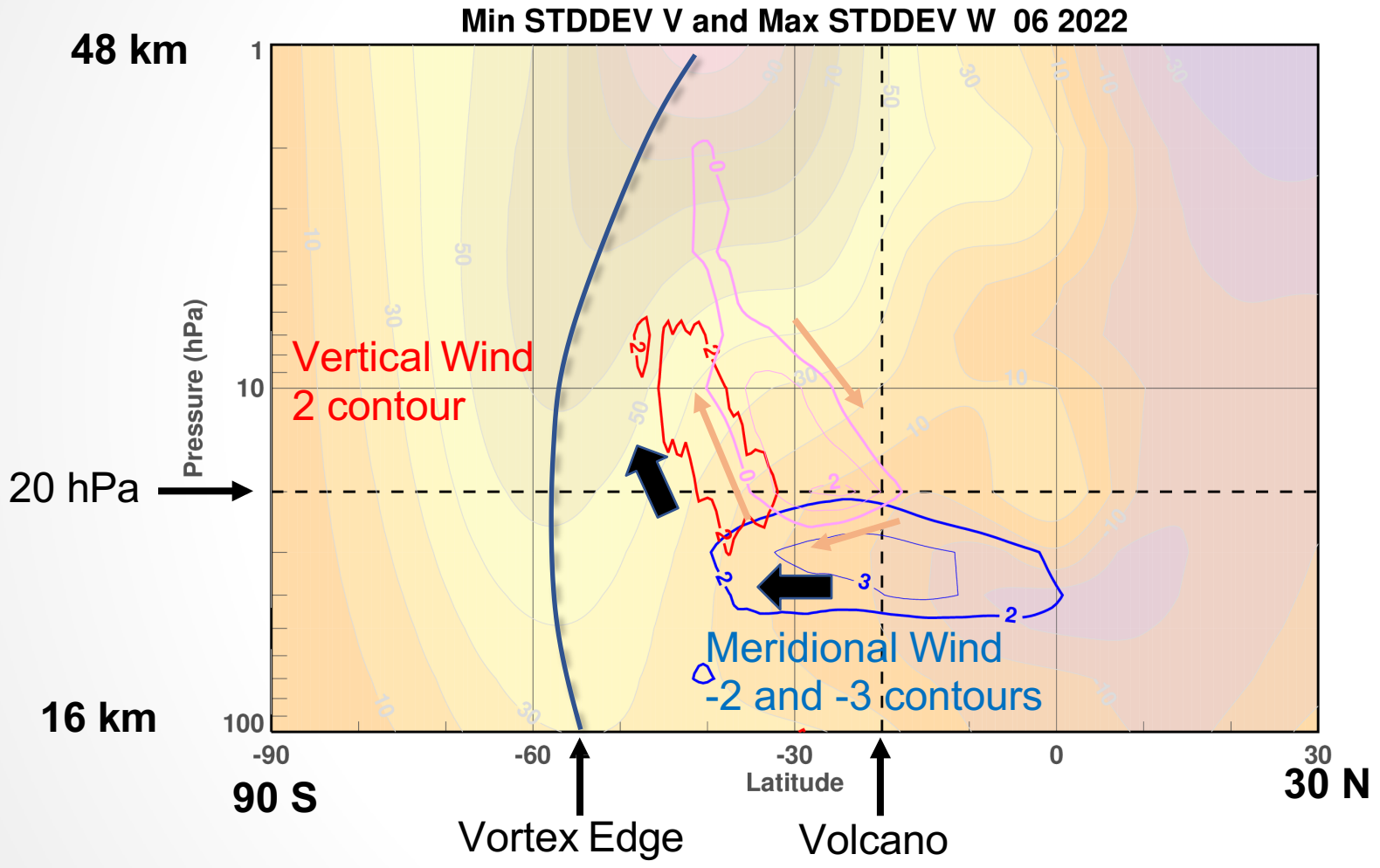
June 2022

Residual Circulation
Record Maximum
Anomaly

WRT 1980-2021 MERRA-2

Vertical residual circulation anomaly was more than **2 standard deviations** above the mean

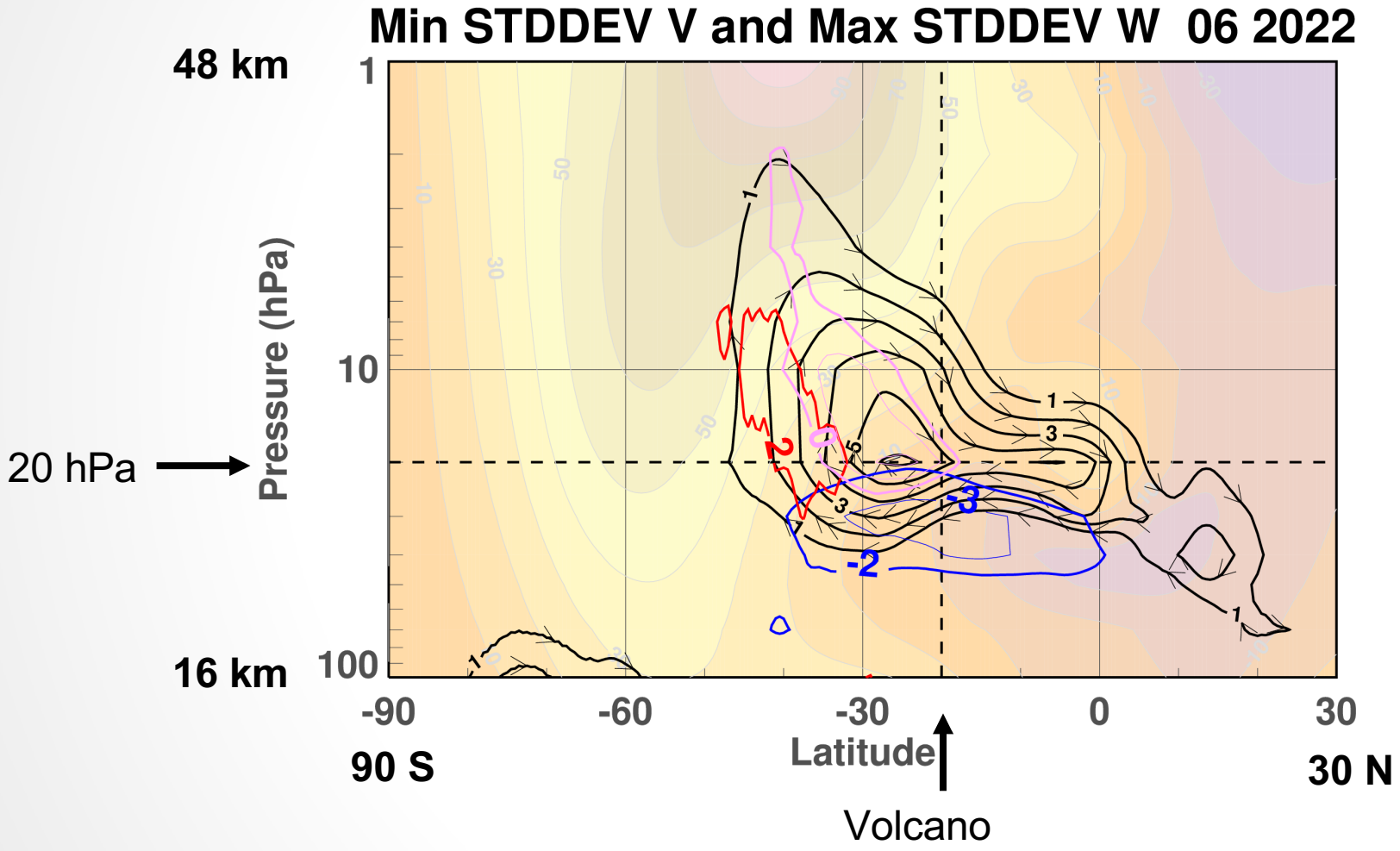
Meridional residual circulation anomaly was more than **3 standard deviations** below the mean



June 2022

WRT 1980-2021 MERRA-2

Clockwise circulation anomaly is centered in the lower stratosphere during June 2022



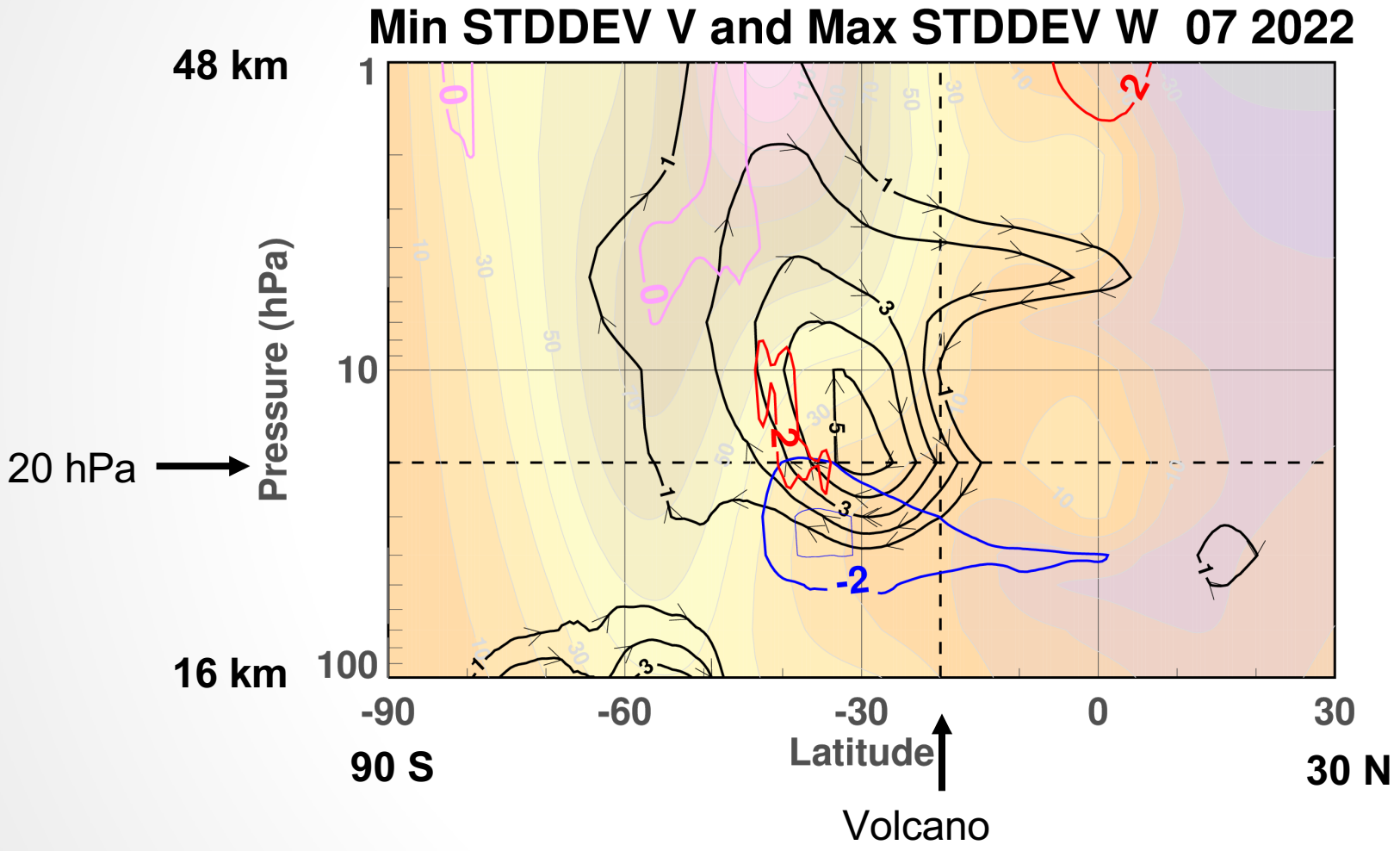
Clockwise Residual Circulation Anomaly

Vertical Wind
2 contour

Meridional Wind
-2 and -3 contours

WRT 1980-2021 MERRA-2

Clockwise circulation anomaly extends to higher altitudes during July 2022



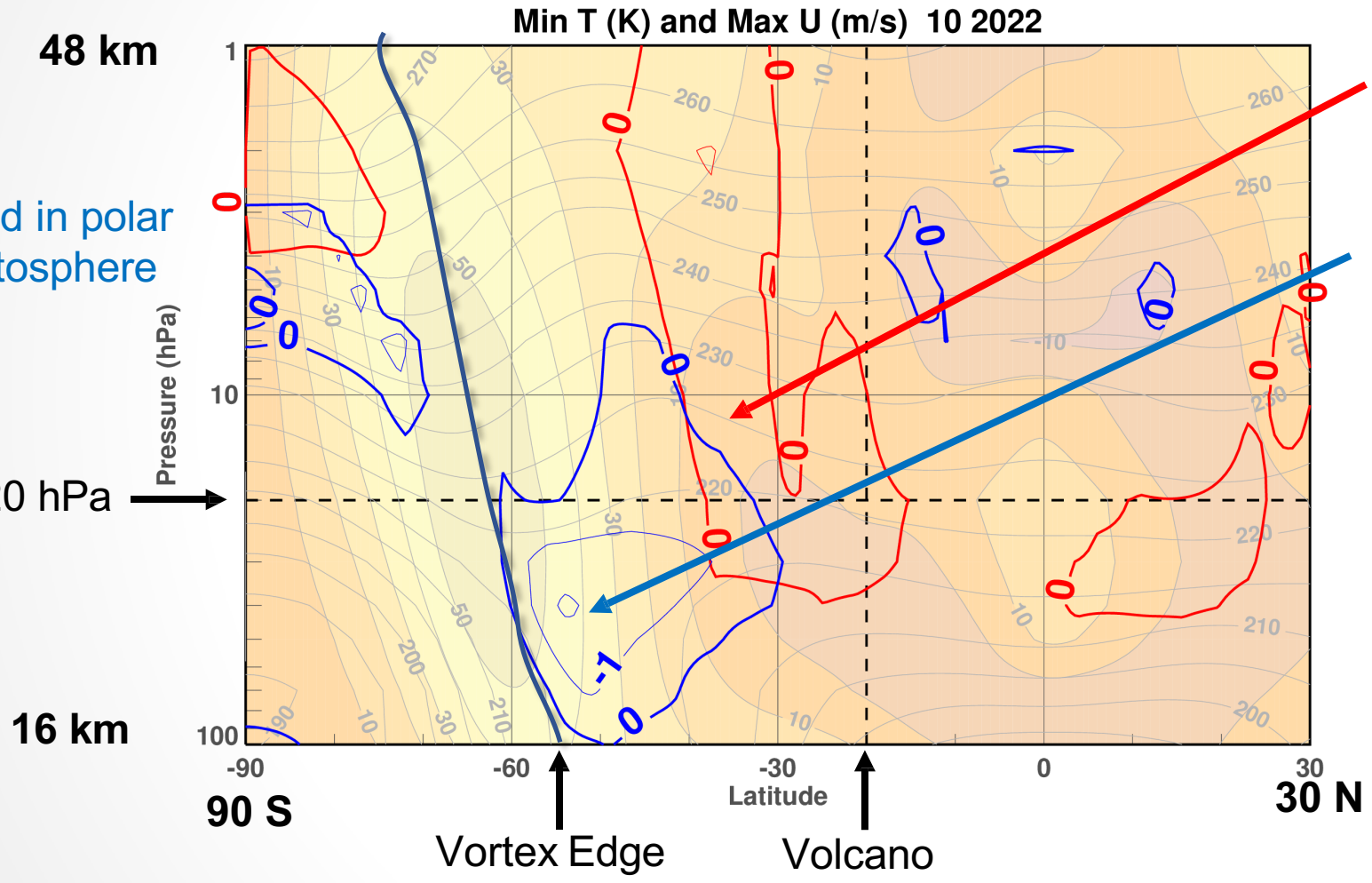
Clockwise Residual Circulation Anomaly

Vertical Wind
2 contour

Meridional Wind
-2 and -3 contours

WRT 1980-2021 MERRA-2

Record low temperatures and strong winds descended in October 2022



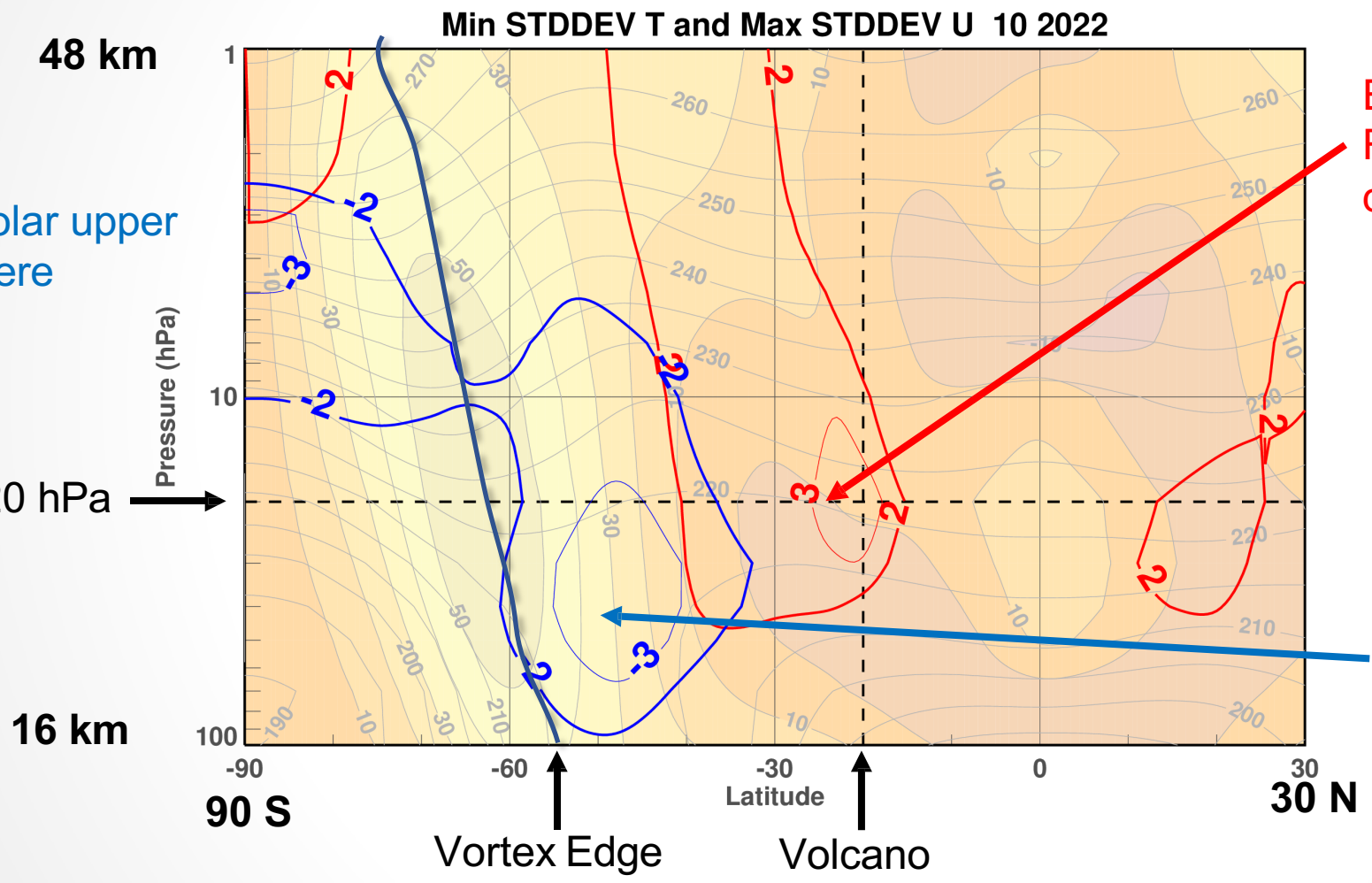
Record Cold in polar upper stratosphere

Exceed Strong Wind Records by less than 5 m/s

Exceed Cold Records by -2K

WRT 1980-2021 MERRA-2

Temperatures were more than 3 standard deviations below the mean
Winds were more than 3 standard deviations above the mean



October 2022

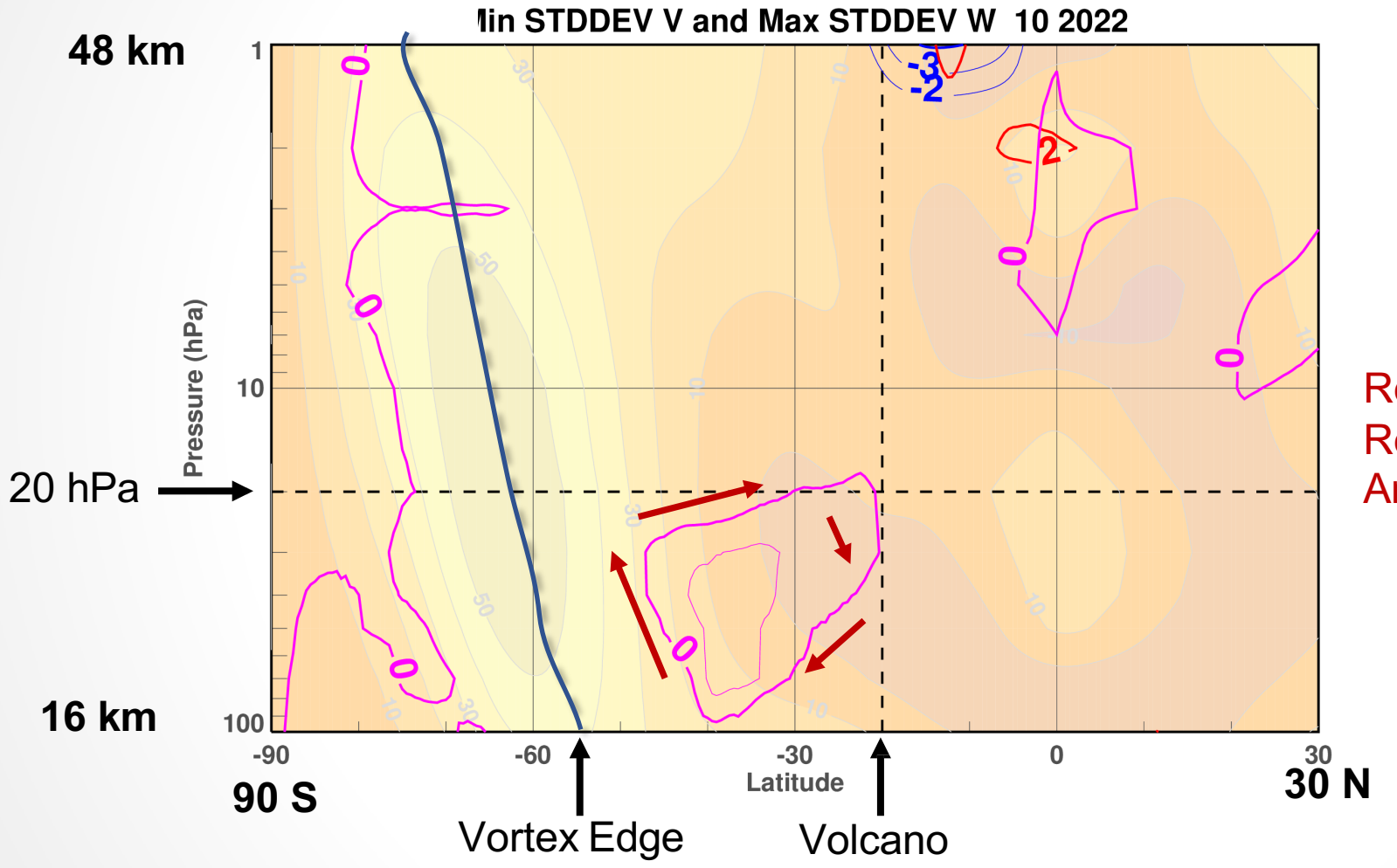
Cold in polar upper stratosphere

Exceed Strong Wind Records by 3 standard deviations

Exceed Cold Records by -3 standard deviations

WRT 1980-2021 MERRA-2

The residual circulation record anomaly descends with time

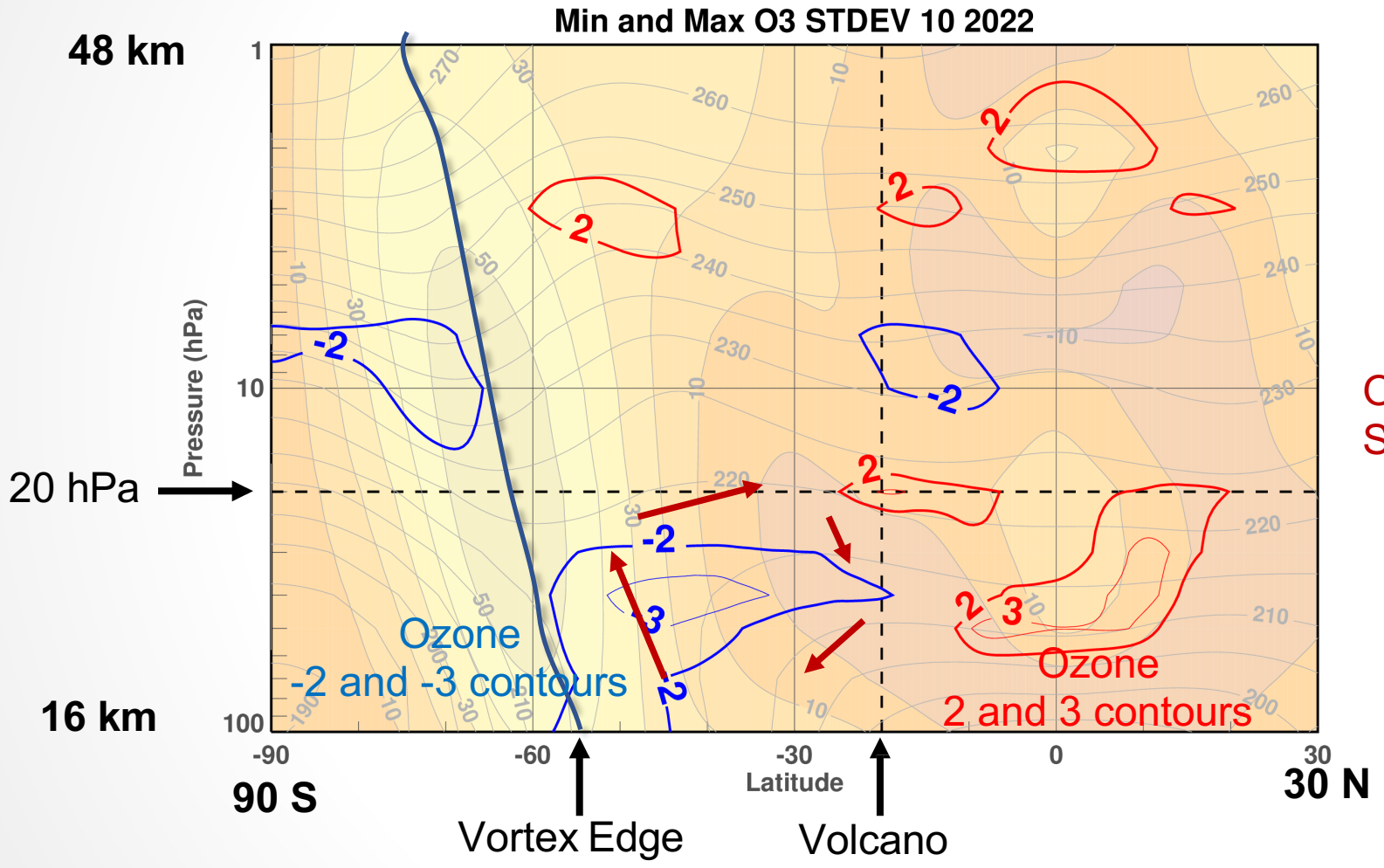


October 2022

Residual Circulation Record Maximum Anomaly

WRT 1980-2021 MERRA-2

Low ozone is associated with the upward circulation anomaly



October 2022

Ozone anomalies
Standard deviations

WRT 1980-2021 MERRA-2

Conclusions

- Data assimilation can provide assessment of model biases and even missing model physics, such as the anomalous water vapor.
- Water vapor from the Hunga-Tonga Hunga Ha-apai eruption disrupted the global middle atmosphere circulation for at least 10 months and is expected to continue for years.
- Future ensemble forecast experiments will include the anomalous water vapor.

Reference: Coy, L., Newman, P. A., Wargan, K., Partyka, G., Strahan, S. E., & Pawson, S. (2022). Stratospheric circulation changes associated with the Hunga Tonga-Hunga Ha'apai eruption. *Geophysical Research Letters*, 49, e2022GL100982. https://doi.org/10.1029/2022GL100982